ACKNOWLEDGEMENT

Alhamdulillah, praise be to Almighty Allah S.W.T., the Most Gracious and the Most Merciful. First and foremost, I would like to express my appreciation and wholehearted sense of gratitude to my supervisor Dr Mohamad Aizat Abas for his continually guidance and constant support. His great interest and assistance has significantly contributed in bringing the success of this research study. Thank you for his invaluable efforts and continuous encouragement in correcting mistakes and also suggesting improvements. My sincere thanks to my co-supervisor, Prof. Ir. Dr. Mohd. Zulkifly Abdullah who has given me a very helpful advice and comments throughout this project.

I would like to express my appreciation to technical staffs of School of Mechanical Engineering, and Jabil Circuit Sdn Bhd especially Mr. Fakhrozi Che Ani for the excellent facilities and warm welcome. I also wish to extend my appreciation to Mr. M.Y. Tura and Mr. A. Marzukhi (Jabil Circuit Sdn Bhd) for their technical support.and also MyBrain scholarship under the Malaysian Ministry of Education.

I would like to acknowledge this research work was partly supported by FRGS grant, FRGS/1/2015/TK03/USM/03/2, Short Term Grant, 60313020 from the Division of Research and Innovation, Universiti Sains Malaysia and Universiti Kebangsaan Malaysia (Research grant–DIP-2014-012).

Last but not least, I would like to convey my deepest appreciation to my beloved family, all friends and colleagues, for their endless love, prayer and encouragement.

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LIST OF ABBREVIATIONS

2-D	2-Dimensional

3-D	3-Dimensional
Ag	Silver
Ag_3Sn	Silver Compound-Tin
Al	Aluminum
Al_2O_3	Aluminum Oxide
$BaTiO_3$	Barium Titanate
BGA	Ball Grid Array
Bi	Bismuth
Ce	Cerium
CFD	Computational Fluid Dynamic
Co	Cobalt
$CoSn_2$	Cobalt Compound-Tin (IMC)
CTE	Coefficient of Thermal Expansion
Cu	Copper
Cu_3Sn	Copper Compound-Tin (IMC)
Cu_6Sn_5	Copper Compound-Tin (IMC)
$(Cu,Ni)_6Sn_5$	Copper-Nickle-Tin (IMC)
DOE	Design of Experiment
DPM	Disperse Phase Method
EDS	Energy Dispersive X-ray Spectroscopy
EIA	Environmental Impact Assessment
EPA	Environmental Protection Agency
EU	European Union
Fe	Iron
Fe_2NiO_4	Iron Nickel Oxide

Fe_2O_3	Iron (III) oxide
FEM	Finite Element Method
FIB	Finely Focused Ion Beam
FSI	Fluid Structure Interface
FVM	Finite Volume Method
FVM-DPM	Finite Volume Method- Disperse Phase Method
HRTEM	High Resolution Transmission Electron Microscope
IC	Integrated Circuit
IMC	Intermetallic Compound
In	Indium
IPC-A-610	Acceptability of Electronic Assemblies
J-STD-001E-2010	Industrial Standard, Requirements for Soldered Electrical and Electronic Assemblies
LBM	Lattice Boltzmann method
MLCC	Multi-Layer Ceramic Capacitor
NEMI	National Electronic Manufacturing Initiative
Ni	Nickle
NiO	Nickle Oxide
O	Oxygen
OSP	Organic Solderable Preservative
Pb	Lead
PCB	Printed Circuit Board
RoHS	Restriction of Hazardous Substances Directive
SAC 405	95.5Sn-3.0Ag-0.5Cu
SAC305	95.5Sn-4.0Ag-0.5Cu

Sb	Antimony
SIMPLE	Semi-Implicit Method
SMC	Surface Mount Component
SMD	Surface Mount Device
SMT	Surface Mount Technology
Sn	Tin
SEM	Scanning Electron Microscope
Sn-Ag-Cu	Tin-Silver-Copper
Sn-Cu	Tin-Copper
Sn-Pb	Tin-Lead
THT	Through Hole Technology
Ti	Titanium
TiO_2	Titanium Dioxide
VOF	Volume of Fluid
Zn	Zinc
ZrO_2	Zirconium dioxide

LIST OF SYMBOLS

ρ	Density of the fluid
t	Time
u	Fluid velocity in x-direction
v	Fluid velocity in y-direction
w	Fluid velocity in z-direction
C_p	Heat Capacitance
T	Temperature
K	Constant
Φ	Polar coordinate
∇	Change of derivative
$\bar{\bar{\tau}}$	Shear stress
G	Gravity
Σ	Surface tension coefficients
θ	Contact angle
γ_{LG}	Surface tension of the liquid-gas
γ_{SL}	The interfacial tension liquid-solid
γ_{SG}	Surface free energy of the solid
$\dot{m}$	Mass transfer
S	Source term
A	Primary-phase volume fraction
f	Fluid volume fraction
F_D	Drag force
$\boldsymbol{u_p}$	Particle velocity
ρ_p	Particle density
d_p	Particle diameter

μ	Kinematic viscosity
F_x	Additional force
D_T	Thermophoric coefficient
F_B	Brownian force
ξ	Zero-mean
S_o	Gaussian random numbers
k_B	Boltzmann constant
C_c	Cunningham factor
Λ	Particle's mean free path
N	Particle number density
F_L	Saffman's lift force
C_D	Drag coefficient
Re	Reynold number
K	Constant, 2.594
d_{ij} , $d_{ik,}d_{ki}$	Deformation tensor
Ψ	Particle sphericity
V_p	Volume
S_p	Surface area of particle
ϕ	the shape factor
P	Pressure
R	Real path
h	Height
Sp	Pad width
Wp	Stencil width
D	Stencil thickness

V_f	Volume fraction
H_s	Circle segment

KAJIAN KAEDAH SEBARAN FASA PARTIKEL BAGI PENDOPAN

ZARAH-NANO DALAM PATERI SAC305

ABSTRAK

Pada masa kini, kebanyakan peranti elektronik terdiri daripada komponen-komponen ultra-halus, oleh itu, untuk memastikan ketahanan yang tinggi dan kekuatan pada pemasangan ultra-halus dan komponen-komponen ini boleh mewakili cabaran besar untuk pereka produk. Banyak penyelidikan tertumpu kepada penggunaan pemateri tanpa plumbum Sn-3.0Ag-0.5Cu (SAC305) dengan pendopan zarah-nano telah diperkenalkan kepada proses pemateri ke arah peningkatan penggunaan pemateri tanpa plumbum tetapi kajian terhad kepada dapatan eksperimen. Dengan pendopan zarah-nano dalam pateri tanpa plumbum, trajektori zarah-nano sepanjand pematerian proses perlu dipantau kerana ini akan mempengaruhi pembentukan ketinggian fillet, lapisan sebatian antara logam (IMC) dan pembentukan mikro-ruang kekosongan. Interaksi dua hala yang menggunakan gabungan kaedah isipadu cecair (VOF) dan kaedah fasa partikel (DPM) telah diperkenalkan dalam kajian semasa untuk menyelidik interaksi antara zarah-halus and pateri lebur. Jenis zarah-halus yang telah didopkan dalam pateri tanpa plumbum SAC305 adalah Titanium Oksida (TiO_2), Nikel Oksida (NiO), Besi (III) oksida (Fe_2O_3) partiekl dengan anggaran diameter ≈20nm dan pada peratus berat zarah yang berbeza iaitu 0.01, 0.05 and 0.15 wt.% pada jenis kapasitor 01005 dengan sendi ultra-halus. Kedua jenis kajian eksperimen dan simulasi dilaksanakan untuk membandingkan kesasihan model baru simulasi DPM. Keputusan yang diperoleh dari eksperimen dpat memvisualisasikan trajektori nanopartikel dengan berkesan pada akhir proses pematerian. Simulasi DPM juga mampu menunjukkan trajektori nanopartikel secara terperinci dalam keadaan pematerian haba SAC305. Di samping itu, keserasian diantara kedua-dua eksperiment dan simulasi data dapat diperoleh dalam kajian ini. Ketinggian fillet dari composite pateri juga memenuhi syarat

minima untuk kapasitor jenis 01005 seperti yang ditetapkan oleh piawaian Industri Elektronik (IPC). Keputusan kajian juga menunjukkan bahawa 0.05wt% NiO nanopartikel mempunyai masa terendah bagi membentuk fillet iaitu 2.65 saat, dan 0.05wt% Fe_2O_3 nanopartikel mempunyai trajektori sebaran zarah yang diagihkan dengan baik. Ini mempengaruhi perencatan pembantukan mikro-ruang dan membentuk lapisan IMC yang nipis. Pendopan nanopartikel dalam SAC305 mengurangkan kebolehan pembentukan IMC yang lebih selari dengan keperluan pembentukan lapisan IMC. Seterusnya, ini menyumbang kepada kebolehbaikan pembetukan pateri yang mana menghalang mikro-ruang terbentuk disebabkan pengedaran tekanan tekanan yang tinggi memberi pengaliran cairan pembentukan pateri yang baik. Kajian interaksi dua hala model VOF dan DPM menunjukkan daya maju dengan pendekatan simulasi dalam proses pematerian component kecil dengan dopan nanopartikel dan cara alternatif ini boleh memberikan kebaikan kepada pendekatan konvensional eksperimen yang mahal.

Katakunci:

SAC305; Nano-komposit pes pateri; Nanopartikel; Titanium oksida (TiO_2); Nikel oksida (NiO); Besi (III) oksida (Fe_2O_3); Simulasi berangka; Kaedah kuantiti terhad (VOF); Kaedah fasa partikel (DPM).

DISPERSE PHASE METHOD PARTICLE STUDY WITH DOPED NANO-PARTICLES IN SAC305 SOLDER

ABSTRACT

Nowadays, most electronic devices consist of miniature components, therefore, to ensure high durability and strength on the assembly of these miniature joints and components can represent huge challenges to the product designer. Vast amount of researches have been concerted to the usage of nano-reinforced Sn-3.0Ag-0.5Cu (SAC305) lead free solder that is introduced to the solder paste for the improvement of the current lead free alloy but the study is limited to experimental findings only. With the inclusion of nanoparticles in the lead free solder, the trajectory of the nanoparticles throughout the soldering process needs to be monitored since it will influence the formation of the fillet height, inter-metallic compound (IMC) layer and micro-void formation. A two way interactions utilizing both volume of fluid method (VOF) and disperse phase method (DPM) are introduced in the current study to account for the interaction between both the nanoparticles and the molten solder. The nano-reinforced particles that are introduced in the SAC305 solder are titanium oxide (TiO_2), nickle oxide (NiO) and Iron (III) oxide (Fe_2O_3) nanoparticles with an approximate diameter of ≈20nm at different weight percentages of 0.01, 0.05 and 0.15 wt.% for application to ultra-fine 01005 type capacitor. Both experimental and simulation studies were conducted to compare the validity of the new DPM based simulation. The results obtained from the experiment can effectively visualize the distribution of the nanoparticles at the end of the reflow process. The DPM simulation on the other hand is capable of showing detail trajectory of the nanoparticles as it undergoes SAC305 thermal reflow. Additionally, good agreement can be seen between both experimental and simulation data obtained for all cases of nanoparticles being used. The fillet height of the nano-reinforced solder also

managed to meet the minimum requirement for 01005 capacitor as set by the Association Connecting Electronics Industries (IPC) standards. The findings also show that 0.05wt% of NiO nanoparticles has the lowest wetting time with 2.65s. Additionally, for 0.05wt% of Fe_2O_3, the trajectory of nanoparticles are well distributed leading to inhibition of void formation and thin IMC layer. The introduction of the nanoparticles in the SAC305 have also shown further retardation on the growth of IMC layer that is favorable since it is aligned with the main requirement of having a thin layer of IMC. Subsequently, this can contribute to good wettability of the solder and managed to inhibit micro-voids formation due to the higher pressure distribution that can promote the flow front propagation of the wetted solder. The study of two-ways interaction of both VOF and DPM models showed the viability of the simulation approach in simulating the miniature soldering process of the molten solder with nanoparticles and can provide a useful alternative to the conventional costly experimental approach.

Keywords:

SAC305; Nanocomposite solder paste; Nanoparticles; Titanium oxide (TiO_2); Nickle oxide (NiO); Iron (III) oxide (Fe_2O_3); Numerical simulation; Finite volume method (FVM) ; Disperse phase method (DPM).

CHAPTER ONE
INTRODUCTION

1.1 Introduction

Electronic packaging is a major discipline within the field of electronic engineering and includes a wide variety of technologies. Nowadays, there are a lot of electronic products available in the market. As time passes, we can observe the revolution of electronics in our modern days. In the ever-changing technology landscape, the industry has responded and will continue to respond to competitive demand in the global marketplace. It can be observed that the advancement of the technology have pushed the human capability beyond imagination in which we can use multi-function smartphones, get aid from robots to replace labour force and enjoy the use of sophisticated yet easy to use household electrical appliances. The requirement placed for high reliability electronic components, miniaturization of the active and passive components are forcing engineers and designers to further optimize the existing manufacturing method (Shah et al., 2006). The electronic components manufacturers have strived to meet the consumer's demand that include highly reliable and low cost components (Alam et al., 2009). The use of smaller passive components in products is expected to reduce the size of the devices manufacture though it would test the mettle of the designers to maintain or even enhance the reliability of the device (Lee, 2002). Assembling these miniature resistors and capacitors presents significant design and assembly challenges.

The advancement in the use of composite lead free solder are essential to cope with the miniaturization of the electronic components. Proper composition of soldering process, material selection, reinforced material selection and the design of

the electronic packaging becomes crucial to maintain the reliability and functionality of the electronic device. The expansion of the electronic components development is moving forward in achieving high reliability of miniaturization and diversification for various electronic packaging applications.

1.2 Surface mount devices and technologies

Most of the major electronics appliances must consist a printed circuit board (PCB) to regulate the functionality of the device. PCBs are boards that mechanically supports and electrically connects electronic components with conductive tracks, pads and other features etched from the copper sheets that is laminated onto non-conductive substrate. One of the primary insulating substrate PCB widely used is the FR-4 glass epoxy PCB.

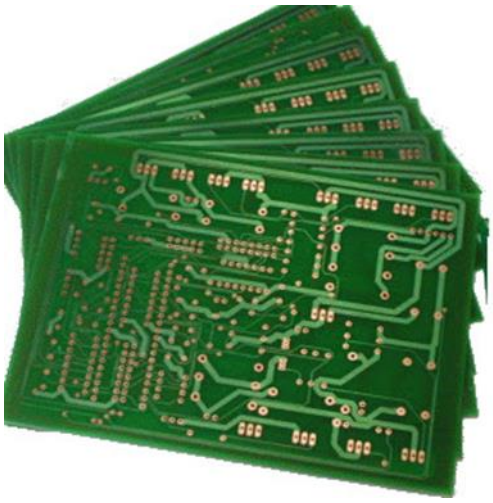

Figure 1. 1: Printed Circuit Board (PCB).

PCB assembly is a necessary step of its manufacturing process, in which either the surface mount technology (SMT) or through-hole technology (THT) is to